A Quantitative Fatty Infiltration Evaluation of the Supraspinatus Muscle

Enhanced Clinical Relevance and Improved Diagnostic Value on Predicting Retear Compared With the Goutallier Classification

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Background: Preoperative assessment of fatty degeneration is important for managing rotator cuff tears. The Goutallier classification is semiquantitative and observer dependent. Discrepancies among surgeons can be prominent. A quantitative method may improve accuracy and reliability in evaluating the exact percentage of fatty infiltration (Fat%).

Hypothesis/Purpose: This study aimed to investigate the correlation between the new quantitative method and the Goutallier classification in assessing fatty infiltration (FI) of the supraspinatus muscle and to explore the use of this method in predicting retear after rotator cuff repair. It was hypothesized that the new method would significantly correlate with the Goutallier classification and be more sensitive to retear.

Study Design: Cohort study (diagnosis); Level of evidence; 3.

Methods: This study included 105 patients who underwent arthroscopic rotator cuff repair for large to massive tears. All patients underwent routine preoperative and 1-year postoperative magnetic resonance imaging and were divided into 2 groups according to tendon healing. Preoperative quantitative Fat% of the supraspinatus muscle was evaluated based on the signal intensity (SI) of the T1-weighted sequence. The Fat% was calculated using the following equation: $SI_{supraspinatus} = SI_{fat} \times Fat\% + SI_{muscle} \times (1 - Fat\%)$. The correlation between the Fat% and the Goutallier grade was determined. Univariate and multivariate analyses were performed to identify the independent risk factors for retear.

Results: The mean preoperative Fat% of the supraspinatus muscle was 23.77 ± 15.96. A significant correlation was found between the Fat% and the Goutallier grade of the supraspinatus muscle ($R = 0.655$; $P < .001$). The overall retear rate was 21.9%; however, functional status significantly improved regardless of cuff healing. Multivariate analysis identified the Fat% ($P = .005$) and the modified Patte classification ($P = .003$) as independent risk factors of retear. The receiver operating characteristic curves showed that the cutoff value of Fat% for predicting retear was 33.2%. Fat% >33.2% possessed superior diagnostic accuracy (79.0%), Youden index (0.513), and positive and negative predictive values (51.6% and 90.5%, respectively) compared with the Goutallier grades.

Conclusion: Although the quantitative method for assessing Fat% of the supraspinatus muscle significantly correlated with the Goutallier classification, the quantitative method is more clinically relevant to retear. Fat% of the supraspinatus muscle >33.2% possessed higher diagnostic value than the Goutallier grades in predicting retear.

Keywords: rotator cuff repair; large to massive tears; quantitative fatty infiltration; retear

Rotator cuff tear is one of the most common upper extremity pathologies, and its prevalence increases with age.[6,43] Arthroscopic rotator cuff repair (ARCR) is the most commonly performed procedure that yields satisfactory clinical results.[25,29,35] However, postoperative retear is of great concern, especially in large to massive rotator cuff tears with reported retear rates of up to 94%.[4,8,15-17,27,29,33,44] Failure of a repaired tendon may lead to inferior clinical outcomes and an increased risk of osteoarthritis.[3,17,28] Recent studies identified fatty infiltration (FI) of the supraspinatus muscle as an independent risk factor for rotator cuff retear, with a cutoff value of Goutallier grade 2.[21,23]

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In the Goutallier classification system, FI was evaluated on T1-weighted scapular Y view magnetic resonance imaging (MRI) according to the relative amounts of muscle and fat judged by eyeballing.[7] Therefore, the Goutallier classification was questioned as being observer dependent, and several studies have reported poor reliability.[13,24,31,37,38] As a semiquantitative method, the output range of the 5-point consecutive grade is limited in the ability to discriminate subtle differences between patients. Consequently, using the Goutallier classification to predict retears may interfere with the surgical planning. Currently, reliable MRI-based quantitative methods require specialized MRI sequences (extra economic cost and imaging acquisition time) and still lack methodical standardization, limiting their wide use.[1,13,20,26,31,34] Therefore, we proposed a new method to quantify Fat% of the supraspinatus muscle based on the signal intensity (SI) on MRI T1-weighted sequences.

We aimed to investigate the correlation between the new quantitative method and the Goutallier classification in assessing FI of the supraspinatus muscle, and to explore the use of this method in predicting retear after rotator cuff repair.

METHODS

Patient Selection

This study was a retrospective analysis of prospectively collected data from patients who underwent ARCR at the author's institution between December 2015 and December 2021. The study protocol was approved by the institutional review board. All patients were given a standardized informed consent form during their stay in our hospital stating that their medical data might be analyzed for education and research purposes. The inclusion criteria were patients with large to massive rotator cuff tear patients (>3 cm, confirmed arthroscopically) who (1) underwent preoperative MRI performed in our hospital for later SI analysis, (2) underwent arthroscopic single-row/suture-bridge repair, (3) had intact or repairable subscapularis tear, and (4) had complete sets of functional assessment and MRI evaluation at least 1 year after surgery. The exclusion criteria were (1) irreparable rotator cuff tear, (2) partial-thickness tear or small- to medium-sized rotator cuff tear, (3) severe arthritic change of the glenohumeral joint (Hamada grade 5), (4) previous surgery on the same shoulder, (5) revision surgery, and (6) loss to follow-up.

Preoperative Variables

We reviewed the medical records of all patients. Preoperative patient variables included age, sex, affected dominant side, symptom duration, trauma history, comorbidities (hypertension and diabetes), and smoking.

All patients underwent preoperative radiography (true anteroposterior view, axillary lateral view, and scapular Y view) of the affected shoulder. Acromiohumeral distance was measured as the shortest distance between the undersurface of the acromion and the humeral head on true anteroposterior radiographs.[22] The severity of the cuff tear arthropathy was graded according to the Hamada classification.[12]

All patients underwent preoperative MRI (1.5 T) examination at our hospital. The tear size, number of involved tendons, and concomitant abnormalities were assessed. Tendon retraction was graded on 2 coronal sections according to the modified Patte stage of Guo et al.[11] Atrophy of the supraspinatus muscle was determined based on whether the supraspinatus muscle crossed the tangent line, extending from the tip of the coracoid to the superior aspect of the scapular spine in the scapular Y view.[45] Fat% of the rotator cuff muscles was evaluated using the Goutallier classification modified by Fuchs et al[7] on the T1-weighted scapular Y view and classified into 5 stages: grade 0, no fat; grade 1, some fatty streaks; grade 2, more muscle than fat; grade 3, equal amounts of fat and muscle; and grade 4, more fat than muscle.

All preoperative radiologic data were assessed by an independent fellowship-trained shoulder surgeon and an independent junior surgeon (J.X. and M.Z.) using picture archiving and communication systems. Both were blinded to the postoperative healing status of the rotator cuff.

New Quantitative Method (Fat%)

We proposed a new method to quantify the Fat% of the supraspinatus muscle based on the SI in the T1-weighted scapular Y view. When FI occurs, the SI of the supraspinatus muscle in the T1-weighted view is primarily contributed by pure muscle tissue and pure fat tissue. The contribution of other tissues (blood vessel, nerves, fascia, etc) can be ignored due to the extremely low content. The

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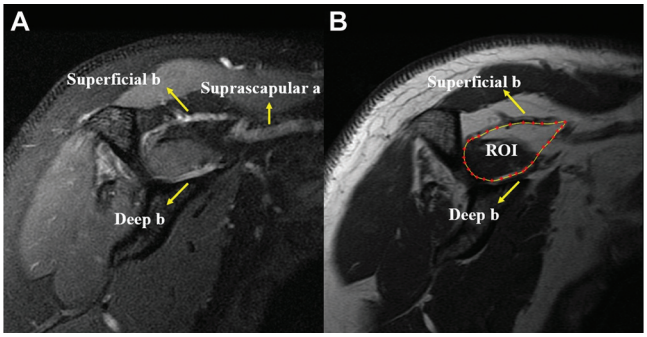

Figure 1. Preoperative sagittal (A) fat-suppressed proton-density T2-weighted and (B) T1-weighted magnetic resonance imaging scans of a right shoulder. These images illustrate that the suprascapular artery (*a*) gives off a superficial branch (*b*) and a deep branch passing on the superficial and deep aspects of the supraspinatus muscle. Consequently, the region of interest (ROI) for the supraspinatus muscle was defined as the area encircled by the superficial branch and deep branch.

pure fat and pure muscle content of the supraspinatus muscle were assumed to be fat% and muscle%. Thus, we derive the first equation: Fat% + Muscle% = 100%. At this point, the SI of the supraspinatus muscle is the mean of the SI of all the pure muscle tissue and pure fat within the supraspinatus muscle. Therefore, we can formulate the second equation: $SI_{supraspinatus} = SI_{fat} \times Fat\% + SI_{muscle} \times Muscle\%$. Combining the previous 2 equations together, we arrived at the final equation:

$$Fat\% = \frac{SIsupraspinatus - SImuscle}{SIfat - SImuscle}.$$

On the basis of the previous anatomic findings, we defined the region of interest (ROI) for the supraspinatus muscle as the area encircled by the first-level branches of the suprascapular artery[5] (Figure 1). If the branches of the suprascapular artery are indiscernible on the T1-weighted scapular Y view, the proton-density fat-suppressed T2-weighted imaging sequence can offer additional help. The SI of the supraspinatus muscle is measured within the ROI.[5] We considered the SI of the deltoid (circular ROI area, 50 mm^2) as the SI_{muscle} and the SI of the extravascular fat inside the supraspinous fossa (circular ROI area, 20 mm^2) as the SI_{fat} (Figures 2 and 3).[2,42] Using the measured SI, the Fat% in the supraspinatus muscle was calculated.

Surgical Technique

All surgeries were performed by 2 senior surgeons (C.J. and Y.Z.). After the induction of general analgesia, patients were placed in the lateral decubitus position with arm traction. Diagnostic arthroscopy was performed via the standard posterior and anterolateral portals. The lateral and posterolateral portals were then established. Biceps tenotomy or tenodesis was considered if obvious tearing, dislocation, or

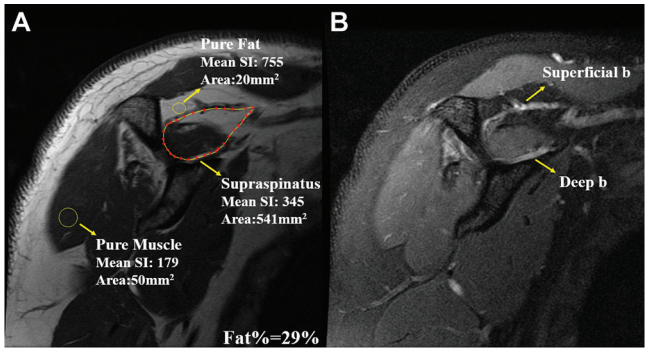

Figure 2. Preoperative (A) T1-weighted and (B) fat-suppressed proton-density T2-weighted MRI scapular Y view of right shoulder. The region of interest (ROI) circle for pure muscle was placed at the lower part of the deltoid muscle, while another ROI circle for pure fat was positioned within the extravascular inside the supraspinous fossa. The ROI for the supraspinatus muscle was the area encircled by the superficial branch (*b*) and the deep branch. The mean signal intensity (SI) and area for each ROI were recorded. According to the previous formula, Fat% is 29% for this patient.

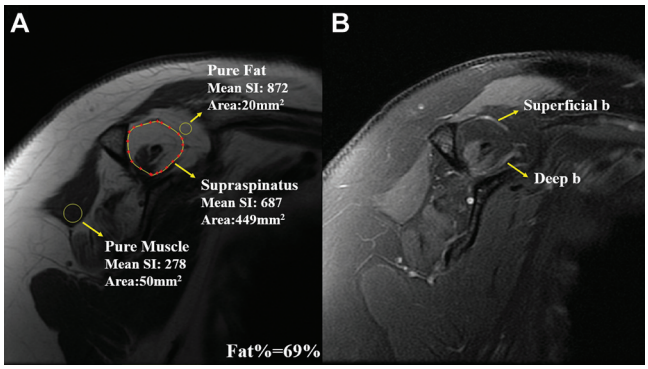

Figure 3. Preoperative (A) T1-weighted and (B) fat-suppressed proton-density T2-weighted scapular MRI Y view of right shoulder. Another example of our quantitative method. Fat% is 69% for this patient. b, branch; SI, signal intensity.

inflammation was observed in the long head of the biceps tendon. Lafosse type 1 subscapularis injuries were treated with debridement, and Lafosse type $\geq$2 subscapularis injuries were treated with either single-row or suture-bridge repair.[19] Once all intra-articular and subscapularis pathologies were addressed, attention was shifted to the subacromial space. On completion of the subacromial bursectomy and acromioplasty, the cuff margin was debrided to identify the tear configuration. A 270° capsular release, complete rotator interval release, and subacromial release were performed. If the torn cuff could be reduced to cover >50% of the footprint without undue tension when the shoulder was abducted to 45°, the suture-bridge technique was used for repair (SwiveLock [Arthrex] and Healix [DePuy Synthes]). Otherwise, single-row repair was performed.

Postoperative Rehabilitation

Postoperative immobilization after surgery was maintained with an abduction pillow for 6 weeks. Passive range of motion exercises were started 3 weeks after surgical repair. Active range of motion exercises and daily activities were allowed 6 weeks after surgery. Resistance training for muscle strengthening with excessive stress was avoided within 6 months postoperatively. All the patients adhered to a uniform rehabilitation protocol under the supervision of the same therapist.

Clinical Evaluation

Anatomic outcomes were evaluated on postoperative 1-year MRI. Sugaya types 4 and 5 were considered as retears.[30,39] Additional MRI might have been performed when a retear was suspected during follow-up. Postoperative MRI scans were assessed by an independent radiologist (Z.G.) to make the final diagnosis of retear.

Functional outcome measures, including the visual analog scale pain score and American Shoulder and Elbow Surgeons score, were collected preoperatively and at 1 year postoperatively. Pre- and postoperative active range of motion (forward elevation and external rotation) were measured with a goniometer. Internal rotation was measured based on the highest vertebral level reached by the thumb: T1 to T12 = 1 to 12, L1 to L5 = 13 to 17, sacrum = 18, buttock = 19, and lateral thigh = 20.[46] In addition, forward elevation and external rotation strength were measured using a digital dynamometer preoperatively and at the 1-year follow-up. An independent examiner (M.Z.) who was blinded to the group assignment performed all functional evaluations.

Statistical Analysis

The normality of continuous variables was assessed using the Kolmogorov-Smirnov test. Normally distributed continuous variables are reported as mean ± standard deviation, whereas nonnormally distributed variables are presented as median (25th percentile, 75th percentile). An independent t test or Mann-Whitney U test was used to analyze the continuous variables. The chi-square test or Fisher exact test was used for categorical variables. A paired t test or Wilcoxon signed-rank test was used to compare the preoperative and postoperative functional outcome measures. The Spearman rank correlation test was used to identify the relationship between the Goutallier classification and the Fat% for the supraspinatus muscle. Multivariate logistic regression analysis was used to determine the independent risk factors associated with retear by inputting the significant variables derived from the univariate logistic regression analysis. To determine the cutoff values of the Fat% and the modified Patte classification for retear, receiver operating characteristic (ROC) analysis with the area under the curve (AUC) was performed. SPSS Statistics Version 22 (IBM Corp) was used to analyze the data, and a P value $<.05$ was regarded as statistically significant.

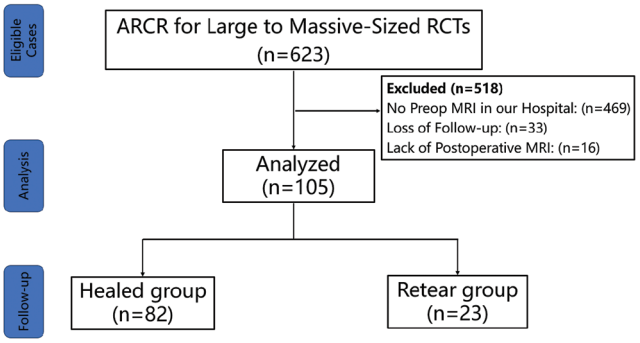

Figure 4. Flowchart of the study population. ARCR, arthroscopic rotator cuff repair; MRI, magnetic resonance imaging; RCT, rotator cuff tear.

The intra- and interobserver reliabilities of the quantitative Fat% were assessed by calculating the intraclass correlation coefficient (ICC). The accuracy, sensitivity, specificity, Youden index (YI), positive predictive value (PPV), and negative predictive value (NPV) were used to evaluate the diagnostic value of fat% and Goutallier grade to predict retear.

RESULTS

Patient Characteristics

Between December 2015 and December 2021, 623 ARCRs were performed for large to massive rotator cuff tears by 2 senior surgeons. A total of 518 patients were excluded because of preoperative MRI performed at other medical centers (n = 469), loss to follow-up (n = 33), and lack of postoperative 1-year MRI scans (n = 16) (Figure 4).

The final study group consisted of 105 patients, with a mean follow-up period of 2.68 ± 0.90 years. The mean age of the patients at surgery was 59.30 ± 9.06 years. The mean preoperative Fat% of the supraspinatus muscle was 23.77 ± 15.96. The other patient characteristics are summarized in Table 1.

Quantitative Fat%

Inter- and Intraobserver Reliabilities. The interobserver reliabilities of the ROI and Fat% for the supraspinatus muscle were excellent, with ICCs of 0.994 and 0.976 in the first assessment and 0.991 and 989 in the second assessment ($P < .001$ for both). Additionally, both examiners demonstrated excellent intraobserver reliability, with ICCs of 0.998 and 0.988 for the ROI of the supraspinatus muscle and 0.978 and 0.989 for fat% of the supraspinatus muscle ($P < .001$ for both).

Correlation Between the Fat% and the Goutallier Grade of the Supraspinatus Muscle. A significant correlation was

TABLE 1
Patient Characteristics (N = 105)[a]

Characteristic	Value
Age, y	59.30 ± 9.06
Sex, male/female, n	47/58
Dominant side affected	82 (78)
Duration of symptoms, mo	5.3 (2, 12)
Trauma event	62 (59)
Hypertension	31 (30)
Diabetes	14 (13)
Smoker	22 (21)
Tear size, large/massive, n	51/54
Subscapularis affected	30 (29)
AHD, mm	6.4 ± 2.4
Hamada grade 1/2/3/4/5, n	71/24/9/1/0
Goutallier grade 0/1/2/3/4, n	
Supraspinatus	11/25/55/12/2
Infraspinatus	11/60/28/6/0
Subscapularis	44/50/11/0/0
Teres minor	80/23/2/0/0
Quantitative Fat% (supraspinatus)	23.77 ± 15.96
Modified Patte grade 1/2/3, n	87/13/5
Tangent sign	19 (18)
Repair technique, SR/SB, n	13/92
Biceps tenotomy/tenodesis, n	49/30

[a]Data are presented as n (%), mean ± SD, or median (25th percentile, 75th percentile) unless otherwise indicated. AHD, acromiohumeral distance; SB, suture bridge; SR, single row.

found between the Fat% and the Goutallier grade of the supraspinatus muscle ($P < .001$) using the Spearman rank correlation test. The correlation coefficient was 0.655, indicating a moderate degree of correlation.

Clinical Outcomes After ARCR

According to the tendon integrity on the 1-year postoperative MRI, 82 and 23 patients were in the healed and retear groups, respectively. The overall retear rate was 21.9%. Statistically significant improvements in all functional outcome measures were observed in both groups, except for internal rotation in the retear group ($P < .05$). No significant differences were found between both groups in any of the shoulder functional values preoperatively and postoperatively ($P > .05$) (Table 2).

Factors Affecting Rotator Cuff Healing

In the univariate analysis, the tear size ($P = .015$), repair technique ($P = .003$), tangent sign ($P < .001$), acromiohumeral distance ($P = .020$), Hamada grade ($P = .007$), Goutallier grade of the supraspinatus muscle ($P = .030$), Fat% ($P < .001$) of the supraspinatus muscle, and modified Patte stage ($P < .001$) were associated with retear after ARCR (Table 3).

In multivariate analysis using logistic regression, only the Fat% of the supraspinatus muscle (OR, 1.14; 95% CI, 1.05-1.31; $P = .005$) and the modified Patte classification (OR, 72.68; 95% CI, 4.35-1215.51; $P = .003$) were independent risk factors for retear after ARCR.

ROC curves revealed that the cutoff values to predict retear after ARCR for large to massive rotator cuff tears were 33.2% for the Fat% of the supraspinatus muscle (AUC, 0.80) and stage 2 for the modified Patte classification system (AUC, 0.79) (Figures 5 and 6).

Diagnostic Value of the Fat% and Goutallier Classification in Predicting Retear

The accuracy, sensitivity, specificity, YI, PPV, and NPV of various cutoff points (Fat%, >33.2%; supraspinatus Goutallier grade ≥2; supraspinatus Goutallier grade ≥3) for FI in supraspinatus muscle are shown in Table 4 to assess their ability to predict retear. The Fat% showed higher accuracy (79.0%), YI (0.513), PPV (51.6%), and NPV (90.5%) compared with the 2 Goutallier indicators. Additionally, it also exhibited satisfactory sensitivity (69.6%) and specificity (81.7%). Although the supraspinatus Goutallier grade ≥2 had the highest sensitivity (82.6%), the accuracy (48.6%), specificity (39.0%), YI (0.216), and PPV (27.5%) were rather low. The supraspinatus Goutallier grade ≥3 had a low sensitivity (21.7%), YI (0.107), and PPV (35.7%).

DISCUSSION

In the present study, we demonstrated a significant correlation between our quantitative method and the Goutallier classification for assessing FI of the supraspinatus muscle. However, the new method is more clinically relevant to retear. Fat% of the supraspinatus muscle >33.2% possessed higher diagnostic value than the Goutallier grades in predicting retear.

FI of the supraspinatus muscle evaluated using the Goutallier classification was reported to be a significant predictive factor for the postoperative anatomic outcomes of ARCR.[9,18,21,23,36] Despite a significant correlation between the Goutallier grades and the quantitative Fat% of the supraspinatus muscle, only the Fat% of the supraspinatus muscle emerged as an independent risk factor for retear in the multivariate analyses, whereas the Goutallier classification did not. Therefore, our findings suggest that the Fat% of the supraspinatus muscle is more clinically relevant for predicting retear. We attributed this difference to the semiquantitative nature of the traditional Goutallier classification. The 5-point ordinal classification system has a restricted output range, limiting its ability to distinguish between subtle differences within or between patients.[20]

In previous research, Liem et al[23] revealed the cutoff value of Goutallier grade 2 in the supraspinatus muscle for postoperative tendon integrity. Consequently, surgeons may not consider ARCR in patients with Goutaller grade ≥2. However, in recent studies, the majority of patients with large to massive tears treated with ARCR had Goutallier grade 2 FI of the supraspinatus muscle (52% in our study) and achieved satisfactory healing rates (78.1% in

TABLE 2
Clinical Outcome After ARCR[a]

Variable	Total (N = 105)	Healed (n = 82)	Retear (n = 23)	*P* Value (Healed vs Retear)
FE, deg				
Preop	110 ± 48.8	110.7 ± 47.0	111.5 ± 56.0	.946
Postop	156 ± 20.1	156.0 ± 20.4	156.1 ± 19.5	.981
P value	**<.001**	**<.001**	**<.001**	
ER, deg				
Preop	35 ± 18.4	33.8 ± 18.4	38.9 ± 18.2	.244
Postop	44 ± 16.0	43.6 ± 17.0	46.3 ± 12.2	.477
P value	**<.001**	**.001**	**<.001**	
IR, deg				
Preop	13.6 ± 3.9	13.8 ± 4.0	12.9 ± 3.4	.315
Postop	12.2 ± 2.7	12.0 ± 2.9	12.7 ± 2.1	.352
P value	**.002**	**.001**	.809	
Strength (FE), kg				
Preop	5.9 ± 4.7	5.6 ± 4.80	7.0 ± 4.2	.218
Postop	9.6 ± 4.4	9.5 ± 4.5	9.9 ± 4.0	.749
P value	**<.001**	**<.001**	**<.001**	
Strength (ER), kg				
Preop	7.9 ± 4.4	7.7 ± 4.3	8.2 ± 4.9	.652
Postop	10.4 ± 4.6	10.4 ± 4.5	10.4 ± 5.3	.933
P value	**<.001**	**<.001**	**<.001**	
ASES score				
Preop	47.8 ± 20.1	48.0 ± 21.5	46.9 ± 14.6	.811
Postop	84.2 ± 12.5	84.6 ± 11.7	82.8 ± 15.1	.541
P value	**<.001**	**<.001**	**<.001**	
VAS score				
Preop	3 (2, 4)	3 (2, 4)	4 (4, 5)	.230
Postop	0 (0, 0)	0 (0, 0)	0 (0, 1)	.458
P value	**<.001**	**<.001**	**<.001**	

[a]Data are presented as mean ± SD or median (25th percentile, 75th percentile). Bold *P* values indicate statistical significance. ARCR, arthroscopic rotator cuff repair; ASES, American Shoulder and Elbow Surgeons; ER, external rotation; FE, forward elevation; IR, internal rotation; postop, postoperative; preop, preoperative; VAS, visual analog scale.

our study).[10,32,40] Given the poor accuracy (48.6%) and specificity (39.0%) observed in our study, using Goutallier grade 2 as the cutoff value may be overly stringent in current clinical practice and could misguide clinical decisions. Furthermore, Tsuchiya et al[41] discovered that patients with preoperative supraspinatus muscle FI classified as Goutallier grade 3 or 4 exhibited a significantly higher retear rate compared with those in the Goutallier grade 0 to 2 group, indicating that Goutallier grade 3 might be an alternative cutoff value. Although accuracy (74.3%) and specificity (89.0%) improved with Goutallier grade 3 as the cutoff value, the sensitivity (21.7%) was far from satisfactory. Considering the relatively low proportion of patients with supraspinatus Goutallier grade ≥3 in the retear group, there is a substantial number of missed retears when using Goutallier grade 3 as the cutoff value.[16,32]

In contrast, the overall diagnostic performance of the Fat% >33.2% to predict retear was superior to those of Goutallier grades 2 and 3, with higher accuracy, YI, PPV, NPV, and satisfactory sensitivity and specificity. With our quantitative method, shoulder surgeons may have a clearer understanding of the extent of FI in the supraspinatus muscle. When the Fat% of the supraspinatus muscle is >33.2%, the repaired cuff might not heal. However, even in cases of nonhealing, patients usually benefited in terms of improved clinical outcome scores in the short-term follow-up. Surgeons and patients should sit together to determine the most appropriate treatment. If ARCR is chosen, patients should be informed of the elevated risk of retear and the potential need for future revision surgery.

In a clinical setting, classification systems for evaluating FI of the rotator cuff muscles should achieve sufficient reliability for consistent communications among shoulder surgeons. The Goutallier classification system is considered as observer dependent, as the degree of FI was determined based on the relative amount of fat and muscle on T1-weighted MRI scans, typically judged by visual inspection.[7] Lippe et al[24] reported a moderate interobserver reliability for the assessing FI of the supraspinatus muscle with the Goutallier classification ($\kappa = 0.41$). Similarly, Slabaugh et al[37] assessed the inter- and intraobserver reliabilities of the Goutallier classification for FI in supraspinatus among 28 examiners, presenting moderate interobserver ($\kappa = 0.43$) and intraobserver ($\kappa = 0.56$) reliabilities. Although efforts were made to increase reliability by dichotomizing or trichotomizing the Goutallier classification, the highest inter- and intraobserver reliabilities were only substantial

TABLE 3
Clinical Factors Associated With Retear on Univariate Analysis[a]

Variable	Healed (n = 82)	Retear (n = 23)	*P* Value
Age, y	59.15 ± 9.72	59.87 ± 6.28	.737
Sex, male/female, n	34/48	13/10	.199
Dominant side affected	63 (77)	19 (83)	.554
Duration of symptoms, mo	5 (3, 12.2)	4 (2, 24.3)	.695
Trauma event	49 (60)	13 (57)	.780
Hypertension	21 (26)	10 (43)	.097
Diabetes	12 (15)	2 (9)	.461
Smoker	17 (21)	5 (22)	.917
Tear size, large/massive, n	45/37	6/17	**.015**
Subscapularis affected	17 (21)	7 (30)	.327
AHD, mm	6.7 ± 2.1	5.4 ± 2.9	**.020**
Hamada grade, 1/2/3/4/5, n	60/18/4/0/0	11/6/5/1/0	**.007**
Goutallier grade, 0/1/2/3/4, n			
Supraspinatus	10/22/41/9/0	1/3/14/3/2	**.030**
Infraspinatus	11/46/22/3/0	0/14/6/3/0	.112
Subscapularis	33/40/9/0/0	11/10/2/0/0	.512
Teres minor	65/16/1/0/0	15/7/1/0/0	.151
Quantitative Fat% (supraspinatus)	19.84 ± 3.54	37.79 ± 16.31	**<.001**
Modified Patte grade, 1/2/3/, n	78/4/0	9/9/5	**<.001**
Tangent sign	10 (12)	9 (39)	**<.001**
Repair technique, SR/SB, n	6/76	7/16	**.003**
Biceps, tenotomy/tenodesis, n	39/20	10/10	.200

[a]Data are presented as n (%), mean ± SD, or median (25th percentile, 75th percentile). Bold *P* values indicate statistical significance. AHD, acromiohumeral distance; SB, suture bridge; SR, single row.

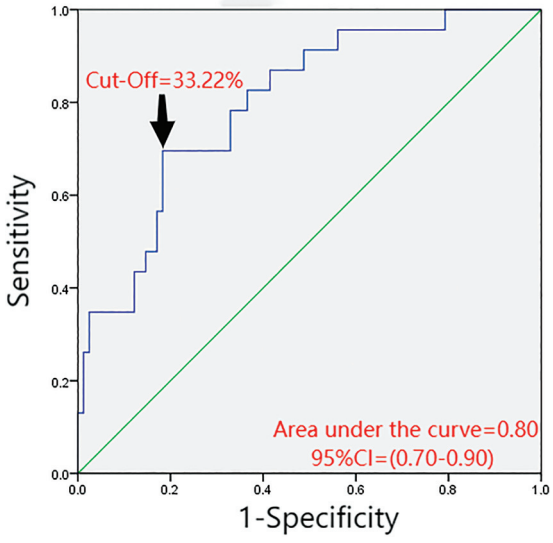

Figure 5. Receiver operating characteristic (ROC) curves for the prediction of retear by quantitative Fat%. The cutoff value to predict retear was 33.22%.

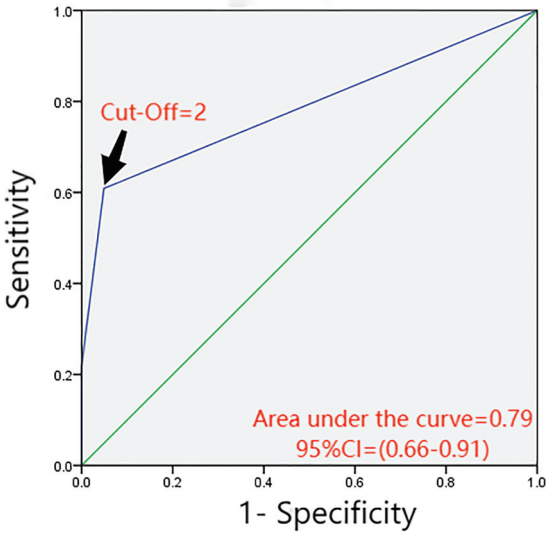

Figure 6. ROC curves for the prediction of retear by tendon retraction. The cutoff value to predict retear was modified Patte grade 2.

with the highest agreement of 77%.[24,37] Compared with previous studies, our quantitative method showed excellent inter- and intraobserver reliabilities. Possible explanations for this improvement include the well-defined border of the supraspinatus muscle and an objective assessment of FI based on SI.[5]

The concept of MRI-based quantitative methods for assessing Fat% is not new in the literature. Pfirrmann et al[34] first implemented proton magnetic resonance spectroscopy to measure fat content in the supraspinatus muscle and found a significant difference in fat content in patients with different Goutallier grades. Subsequent

TABLE 4
Diagnostic Value of Fat% and Goutallier Grade to Predict Retear[a]

Characteristic	Accuracy	Sensitivity	Specificity	YI	PPV	NPV
Fat% >33.2%	79.0 (83/105)	69.6 (16/23)	81.7 (67/82)	0.513	51.6 (16/31)	90.5 (67/74)
SSP Goutallier grade ≥2	48.6 (51/105)	82.6 (19/23)	39.0 (32/82)	0.216	27.5 (19/69)	88.9 (32/36)
SSP Goutallier grade ≥3	74.3 (78/105)	21.7 (5/23)	89.0 (73/82)	0.107	35.7 (5/14)	80.2 (73/91)

[a]Data are presented as % (n/N). NPV, negative predictive value; PPV, positive predictive value; SSP, supraspinatus; YI, Youden index.

studies have adopted the chemical shift–based sequence (Dixon or IDEAL [iterative decomposition of water and fat with echo asymmetry and least-squares estimation] sequence) to quantify FI in the supraspinatus muscle and demonstrated a significant correlation between quantitative methods and the Goutallier classification.[13,31] However, currently accepted MRI-based quantitative methods inevitably require specialized MRI sequences, thereby increasing image acquisition time and economic cost. Furthermore, MRI-based quantitative methods still lack methodological standardization, which limits their publication in clinical use. To address these limitations, we developed an easily accessible and objective method to quantify the Fat% based on SI on T1-weighted MRI scans. We also observed a significant correlation (R = 0.655; P < .001) between the Goutallier classification and our quantitative method, indicating its clinical feasibility. In addition, our study is the first to present a quantitative cutoff value of Fat% in the supraspinatus muscle for predicting retear after ARCR.

Limitations

Our study has several limitations. First, only a relatively small number of cases were available, as most patients underwent preoperative MRI at other medical centers. Therefore, the power of the multivariate analysis may be limited. Second, the retrospective design of this study may have caused a selection bias. Third, the follow-up time was relatively short (1 year postoperatively). However, we believe that it is sufficient to evaluate retear as the majority of retears occur within 12 months after surgery.[14] Fourth, the ROI of the supraspinatus muscle was defined as the area encircled by the first-level branches of the suprascapular artery according to a previous anatomic study.[5] Considering the fact that the anatomic study was conducted on normal rotator cuffs, patients with rotator cuff tears might exhibit alternations in their anatomic structures, which could be a potential bias in determining the ROI of the supraspinatus muscle in this study. In addition, we implemented the new method to quantify infraspinatus Fat%, but found only a weak correlation between Fat% and Goutallier grade, and Fat% was not a retear risk factor. We believe that this discrepancy stems from our choice of reference SI_{fat}. Despite fat appearing uniformly white on T1-weighted MRI scans, SI varies with distance from the coil. In our study, we used the extravascular fat in the supraspinous fossa as the reference, which may have affected results for the infraspinatus muscle. Future studies will explore a more suitable reference for the infraspinatus muscle. Finally, we did not compare our quantitative method with the currently accepted MRI-based quantitative methods. To justify the clinical application of our quantitative method, future studies are required to determine the correlation between our method and the existing MRI-based quantitative methods.

CONCLUSION

Although the quantitative method for assessing Fat% of the supraspinatus muscle significantly correlated with the Goutallier classification, the quantitative method is more clinically relevant to retear. Fat% of the supraspinatus muscle >33.2% possessed higher diagnostic value than the Goutallier grades in predicting retear.

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